Petrologic and Structural Relations of the Edsel Ford Range, Marie Byrd Land, to other Antarctic Mountains

II. Northeastern Borderlands of the Ross Sea: Glaciological Studies in King Edward VII Land and Northwestern Marie Byrd Land

By

F. ALTON WADE

A DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY WITH THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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EDSEL FORD RANGE
Air-photo of central portion of the range.

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PETROLOGIC AND STRUCTURAL RELATIONS OF THE EDSEL FORD RANGE, MARIE BYRD LAND, TO OTHER ANTARCTIC MOUNTAINS

BY F. ALTON WADE

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INTRODUCTION

The Edsel Ford Range is located in northwest Marie Byrd Land. It extends for approximately 150 miles along the eastern boundary of Sulzberger Bay and acts as a retaining wall to check the advance of ice from the Rockefeller Plateau. The geographic setting is shown in Figure 1. This section of the Antarctic was discovered in 1929 by Admiral Byrd during an exploratory flight that carried his plane to within about 100 miles of the range. A reconnaissance map of the area was constructed from the photographs taken during the flight.[1] A four-man sledge party led by Paul Siple, which included in its personnel Stephenson Corey, Olin Stancliff, and the writer, spent 39 days of the short field season in these mountains. From the observations made and from the results of the petrographic analyses of the rocks collected, comparisons have been made and relationships of the Edsel Ford Range with the known regions of the Antarctic have been tentatively established.

[1] E. Byrd: *The flight to Marie Byrd Land*, Geogr. Rev., vol. 23 (1933).

STRUCTURE OF THE EDSEL FORD RANGE

PHYSIOGRAPHY

The Edsel Ford Range is composed of a series of mountain groups whose present configurations are the combined results of the folding of a series of sedimentary formations, the intrusions of great masses of igneous rocks, and the erosive action of local glaciers and the continental ice sheet (Pl. 1). Considered individually, the mountain groups composing this range present varied and dissimilar physiographic expressions. Those composed largely of folded metamorphosed sediments are usually somewhat pyramidal and the peaks of such groups are connected by snow-covered ridges. Mt. Saunders and the Raymond Fosdick Mountains have serrated outlines. Mt. Rea is a cluster of peaks with steep faces and flat tops. In most cases two factors have predominated in the production of the present shapes: first, the attitude of the major joint systems, and, second, the erosive action of local glaciers. The tremendous force produced by water freezing in joints has caused the splitting off of great blocks of rock which are now piled up at the base of the cliffs or have sunken out of sight in the ice. Where the dip of the major joints is nearly vertical, as it is at Mt. Grace McKinley and at Mt. Rea, this action has produced smooth, steep cliffs. More gentle dips result in more gentle slopes.

The great valleys separating the various mountain groups owe their existence principally to zones or planes of weakness in which erosive action has been greatest. Major joint systems are essentially parallel to each of the indentations in the hypothetical coast line. As these valleys are the principal outlets to the sea, they have been greatly deepened by the ice moving down them.

The sedimentary formations are intensely folded and the beds at most of the observed outcrops are nearer vertical than horizontal. However, in the Chester Mountains, the beds of slate composing one small peak are nearly flat-lying and relatively undisturbed (Pl. 2, fig. 1), while the beds of the surrounding peaks are greatly disturbed.

The major fold axes are not parallel. There appears to be a spreading of the axes; those to the south of John Hays Hammond Inlet extend in a direction parallel with King Edward VII Land Peninsula[2] and those to the north of the Inlet swing northward (Fig. 1). This folded area was intruded by great masses of granite and granodiorite. A contact of the metamorphosed sediments and the intrusives is exposed on the northernmost peak of Mt. Rea. Great fingers of granite intrude the black schists, cross-cutting structure in the main (Pl. 2, fig. 2). Stoped blocks

[2] F. A. Wade: *Northeastern borderlands of the Ross Sea: glaciological studies in King Edward VII Land and northwestern Marie Byrd Land*, Geogr. Rev., vol. 27 (1937).

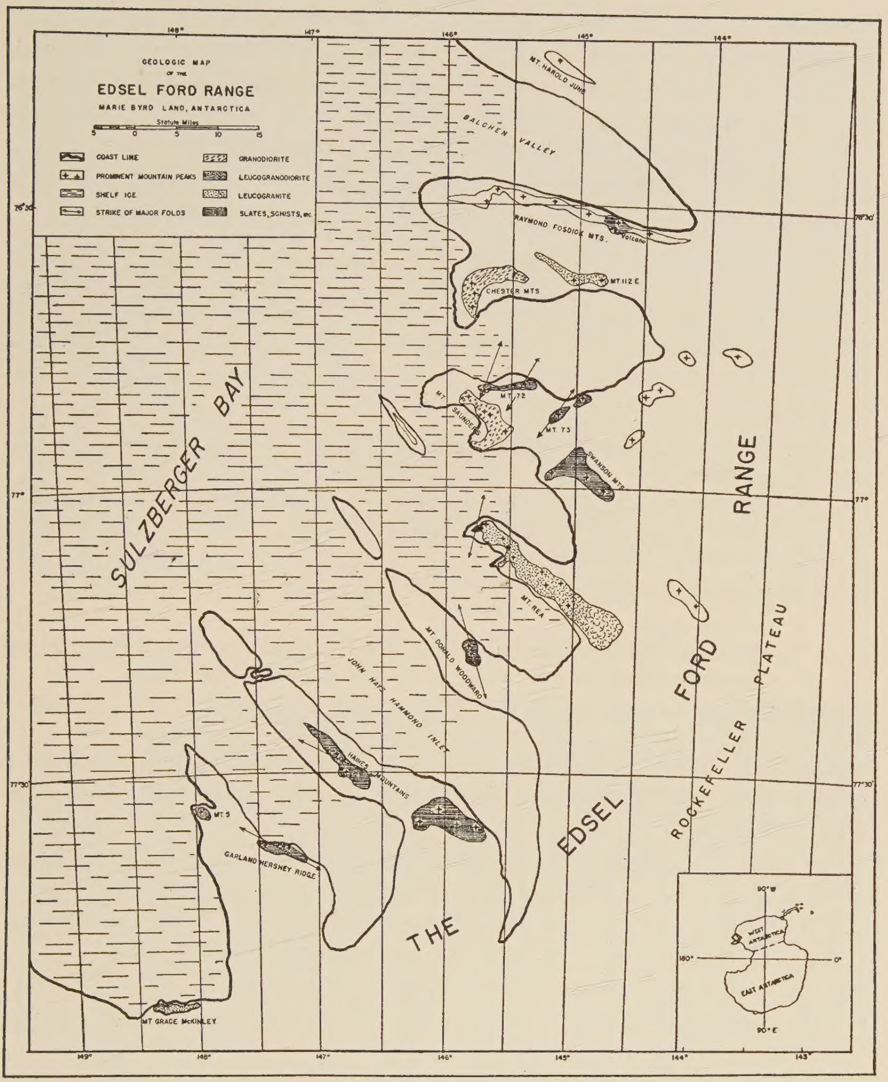
GEOLOGIC MAP
OF THE
EDSEL FORD RANGE
MARIE BYRD LAND, ANTARCTICA
Statute Miles
5 0 5 10 15
COAST LINE
PROMINENT MOUNTAIN PEAKS
SHELF ICE
STRIKE OF MAJOR FOLDS
GRANODIORITE
LEUCOGRANODIORITE
LEUCOGRANITE
SLATES, SCHISTS, etc.
MT. HAROLD JUNE
BALCHEN VALLEY
RAYMOND FOSDICK MTS.
Volcano
MT 112 E
CHESTER MTS
MT 72
MT 73
MT SAUNDERS
SWANSON MTS
MT. REA
MT DONALD WOODWARD
JOHN HAYS HAMMOND INLET
HAINES MOUNTAINS
MT. 5
GARLAND HERSHEY RIDGE
MT GRACE McKINLEY
SULZBERGER BAY
THE EDSEL FORD RANGE
ROCKEFELLER PLATEAU
WEST ANTARCTICA
EAST ANTARCTICA
90° W
90° E
180°
0°
149°
148°
147°
146°
145°
144°
143°
76°30'
77°
77°30'

FIGURE 1.—*Geologic map of the Edsel Ford Range*

of the schist can also be seen high up on the face of a nearby granite peak (Pl. 3, fig. 1).

The physiographic expression of the range as a whole resembles the outlying foothills of the Queen Maud Range,[3] but certainly the tabular-topped mountains, characteristic of this and other ranges of the great

[3] L. M. Gould: *Structure of the Queen Maud Mountains, Antarctica,* Geol. Soc. Am., Bull. 46 (1935) p. 974.

Antarctic Horst, are not comparable. The Queen Maud foothills are composed of pre-Cambrian gneisses, schists, and intrusive granites and owe their present forms to frost action and the erosive action of moving ice. The similarity stops here, for the series of younger folded sediments is entirely lacking and there is no evidence of the pre-existence in the Edsel Ford Range of a series of sediments similar to the Beacon sandstone series which formerly capped the Queen Maud foothills.

PETROLOGIC SUMMARY

The rocks composing the mountains of the Edsel Ford Range as represented by the specimens collected by the Eastern Sledge party may conveniently be grouped as follows:

I. Igneous rocks
   a. Massive intrusives. Granodiorite, leuco-sodaclase granodiorite, leucogranite
   b. Dike rocks. Porphyritic diabase, diabasic diorite, granite porphyry, granodiorite, leuco-sodaclase granodiorite, amphibole peridotite
   c. Extrusive. Olivine basalt

II. Metamorphic rocks
   a. Granite gneiss
   b. Metamorphosed sediments. Biotite schist, orthoclase-biotite schist, biotite-orthoclase schist, sericite schist, orthoclase-sericite schist, slate

III. Sedimentary rock. Arkose

The following were collected as erratics: leuco-sodaclase granodiorite, granodiorite, leucogranite, olivine basalt, slate, phyllite, and biotite-muscovite schist.

In Table 1 are listed the mineralogical analyses of the massive intrusives and in Table 2 those of the principal dike rocks.

With but few exceptions the igneous rocks of this area are high in sodium and potassium. The small percentages of mafic minerals are especially worthy of note. In only one massive intrusif (Mt. Saunders) is a pyrabole an essential constituent. The plagioclases of the granites and granodiorites are commonly zoned (Pl. 3, fig. 2). The olivine basalt is from an extinct volcano located on the southern slope of the Raymond Fosdick Mountains (Fig. 1). From the relations of the extruded ash and fragmental material to the ice, it is evident that the eruption continued after the inundation of the region by ice.

Of the metamorphic rocks observed and studied the only one which might be considered to represent the basement complex of East Antarctica[4] is the granite gneiss of the Raymond Fosdick Mountains. The

[4] *Op. cit.*, p. 980.

FIGURE 1. FLAT-LYING SEDIMENTARY FORMATIONS
In Chester Mountains. Dip of beds in the peak in right background is approximately 50 degrees.

FIGURE 2. LEUCOGRANITE STRINGERS
In schists at Mt. Rea.

FIGURE 1. STOPED BLOCK OF BLACK SCHIST
In granite of Mt. Rea.

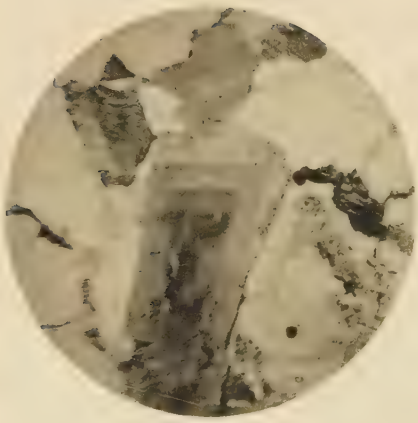

FIGURE 2. ZONED PLAGIOCLASE
In Mt. Rea granite. Crossed nicols, X 53.

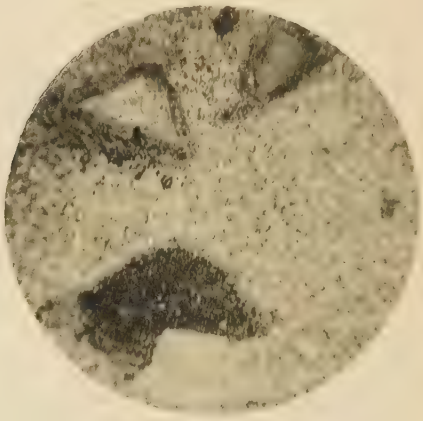

FIGURE 3. ORTHOCLASE-SERICITE-SIDERITE SCHIST
Haines Mountains. Siderite partly altered to limonite. Crossed nicols, X 20.

ROCKS OF EDSEL FORD RANGE

metamorphosed sedimentary series has not undergone such intense alterations as the basement gneiss, and no minerals characteristic of high temperature metamorphism were noted in the thin sections examined. Recrystallization varies in intensity, and cataclastic texture is excep-

TABLE 1.—*Mineralogical composition of the Massive Intrusives of the Edsel Ford Range of Marie Byrd Land, Antarctica*

Mineral	Specimen									
	1	2	3	4	5	6	7	8	9	10
Quartz	21.8	41.5	31.5	21.3	26.2	13.6	7.2	18.8	5.1	10.6
Orthoclase	18.7	44.2	49.9	.....	13.3	18.0	15.1	24.6	15.4	24.8
Microperthite	.....	.....	.....	65.5	.....	.....	.....	3.9	.....	43.3
Albite	56.6	.....	.....	.....	.....	.....	.....	.....	.....	.....
Albiclase	.....	.....	.....	.....	.....	.....	68.6	.....	.....	18.5
Oligoclase	.....	.....	.....	9.8	.....	.....	.....	.....	.....	.....
Andesine	.....	7.7	16.8	.....	40.7	48.8	.....	41.7	58.9	.....
Muscovite	2.8	.....	p	1.7	.....	.....	0.5	.....	.....	.....
Biotite	.....	6.7	1.7	1.7	17.3	17.9	8.5	10.9	14.3	2.7
Hornblende	.....	.....	.....	.....	2.4	1.7	.....	.....	.....	.....
Magnetite	.....	p	p	.....	p	p	.....	.....	4.9	p
Apatite	p	p	p	p	p	p	p	p	1.4	p
Zircon	.....	.....	p	p	p	p	p	p	p	p
Beryl	p	.....	.....	.....	.....	.....	.....	.....	.....	.....
Topaz	p	.....	.....	.....	.....	.....	.....	.....	.....	.....
Calcite	.....	.....	.....	.....	p	p	.....	.....	.....	.....
	99.9	100.1	99.9	100.0	99.9	100.0	99.9	99.9	100.0	9.99

p=present in thin section.
1. Leuco-sodaclase granodiorite. Mt. Grace McKinley.
2. Leucogranite. Mt. Grace McKinley.
3. Leucogranite. Mt. Grace McKinley.
4. Leucogranite. Mt. Rea.
5. Granodiorite. Mt. Saunders.
6. Granodiorite. Mt. Saunders.
7. Sodaclase granodiorite. Fosdick Mountains.
8. Sodaclase granodiorite. Chester Mountains.
9. Granodiorite. Fosdick Mountains.
10. Leucogranite. Chester Mountains.

tional. One bed of arkose has been only very slightly altered. The outstanding mineralogic characteristic of the schistose rocks is the prevalence of feldspar over quartz, indicating that the original sediments had suffered little decomposition. The presence of siderite (Pl. 3, fig. 3) is noteworthy. No fossils were found.

From the rather meager data it is concluded that the sequence of events was as follows: deposition of a great series of arkosic sandstones

and shales on the pre-Cambrian basement rocks, close folding of this sedimentary series accompanied by the deep-seated intrusion of acid

TABLE 2.—*Mineralogical composition of the dike rocks from the Edsel Ford Range of Marie Byrd Land, Antarctica*

Mineral	Specimen						
	1	2	3	4	5	6	7
Quartz	.....	10.0	.....	13.2	.....	15.9	9.3
Orthoclase	.....	30.0	2.4	27.7	.....	20.0	24.7
Oligoclase	.....	.....	.....	51.5	.....	.....	.....
Andesine	.....	.....	50.6	.....	.....	55.5	42.0
Labradorite	57.4	.....	.....	.....	4.0	.....	.....
Bytownite	.....	40.0	.....	.....	.....	.....	.....
Biotite	.....	20.0	1.8	7.6	.....	10.6	24.0
Chlorite	23.0	.....	.....	.....	.....	.....	.....
Muscovite	.....	.....	.....	p	.....	.....	.....
Augite	8.6	.....	.....	.....	.....	.....	.....
Hornblende	.....	.....	45.2	.....	88.0	.....	.....
Olivine	.....	.....	.....	.....	8.0	.....	.....
Magnetite	9.8	.....	p	.....	p	p	p
Apatite	p	.....	p	p	p	p	p
Zircon	.....	.....	.....	p	.....	p	p
Calcite	1.0	.....	.....	.....	.....	.....	.....
Hematite	.....	.....	p	.....	p	.....	.....
	99.8	100.0	100.0	100.0	100.0	100.0	100.0

p=present in thin section.
1. Porphyritic diabase. Mt. Grace McKinley.
2. Melagrangabbro. Mt. Grace McKinley.
3. Dibasic diorite. Mt. Rea.
4. Granodiorite. Fosdick Mountains.
5. Amphibole peridotite. Fosdick Mountains.
6. Granodiorite. Mt. Saunders.
7. Granodiorite. Mt. Saunders.

magma, a long period of erosion, glaciation, and the extrusion of olivine basalt during the Pleistocene.

RELATION OF THE EDSEL FORD RANGE TO THE REST OF THE ANTARCTIC CONTINENT

Antarctica has long been divided into two natural subdivisions. Structure and petrography are at great variance with each other in the two areas. East Antarctica embraces all of that vast region lying to the south of the Atlantic and Indian oceans and extending to an imaginary line connecting the Ross and Weddell seas. West Antarctica has been largely limited to the island province south of South America now known as the Antarctic Archipelago (*See* Figs. 1 and 2). The extensive and until recently unexplored area between the two has been variously

classified by students of Antarctic geology.[5] Northwest Marie Byrd Land with its Edsel Ford Range is located in this area, and the investigation of these mountains was undertaken primarily to secure information to aid in fixing the position of the line dividing these structural and petrographic units.

Physiographically, West Antarctica is an almost mirror image of Tierra del Fuego. Structurally and petrographically they are also very similar. The intrusive gabbros, granodiorites, and granites of this area are similar in structure and composition to those of the Andes.[6] The Mesozoic sediments were folded from west to east in late Tertiary time.[7] Briefly, then, the principal characteristics of West Antarctica are (1) eruptive rocks of the "Pacific type" and (2) extensive folds.

Structurally and petrographically East Antarctica is very different. The basement complex is composed of pre-Cambrian gneisses, schists, limestones, and graywackes, overlain by a tremendous series of nearly flat-lying Paleozoic and early Mesozoic sandstones, arkoses, and shales.[8] Near the close of the Mesozoic East Antarctica was subjected to a period of block faulting.[9] The great Antarctic Horst which forms the western boundary of the Ross Sea was formed at that time. A period of volcanic activity accompanied and followed these tectonic disturbances and is continuing even today (Mt. Erebus). There is no evidence of Antarctandean folds in this area. The petrographic investigations of Prior,[10] Stewart,[11] and others have shown that the igneous rocks are of the so-called "Atlantic type." Briefly, then, we may think of East Antarctica as a faulted plateau region whose rocks are characterized by a relatively high content of sodium and potassium.

The only areas in this great expanse of land between the Ross Sea and the Antarctic Archipelago which had been examined by field parties prior to the second Byrd Antarctic Expedition were Scott's Nunataks and the Rockefeller Mountains, both in King Edward VII Land (Fig. 2). From his petrographic investigations of the rocks from Scott's Nunataks, Schetelig[12] concludes, "The resemblance of the rock-complex from Scott's Nunataks to the pre-Gondwana basement rock-complex of South Victoria

[5] Griffith Taylor: *Antarctic adventure and research* (1930) p. 89, New York.
L. M. Gould: *op. cit.*, p. 982-983.

[6] J. G. Anderson: *On the principal geological results of the Swedish Antarctic Expedition*, 10th Congr. geol. intern., Mexico, C. R. (1906) p. 729.

[7] Griffith Taylor: *op. cit.*, p. 101.

[8] T. W. E. David: *Antarctica and some of its problems*, Geogr. Jour., vol. 43 (1914) p. 624-626.

[9] L. M. Gould: *op. cit.*, p. 979.

[10] G. T. Prior: *Report on rock specimens, etc.*, Natl. Antarctica Expedition, 1901-1904, Natural History, vol. 1, Geology.

[11] Duncan Stewart, Jr.: *A contribution to Antarctic petrography*, Jour. Geol., vol. 42 (1934) p. 550.

[12] J. Schetelig: *Report on the rock specimens collected on Roald Amundsen's South Pole expedition*, Vidensk.-Selsk. Christiania, Skrifter I, Math.-Nat. Klasse (1915) p. 1-31.

Land with gneisses and intrusive granites seem to show the close connection of King Edward Land to South Victoria Land." Stewart[13] states, ". . . after comparative studies of Gould's specimens from King Edward VII Land with the specimens from the Queen Maud Range of

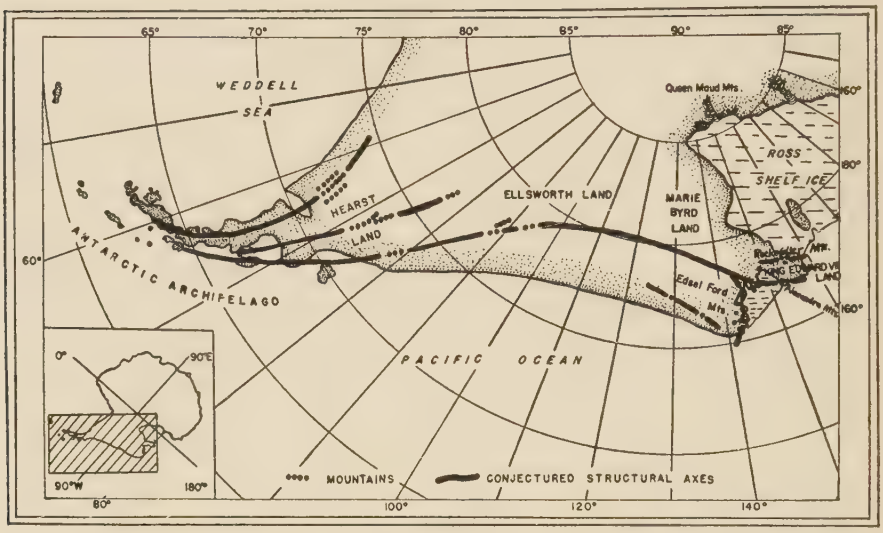

FIGURE 2.—*Conjectured structural axes of West Antarctica*
(In part, after Joerg)

South Victoria Land and with rocks collected in the Antarctic Archipelago by the Expedition Antarctique Française, 1903-05, it is concluded that the rocks of the Rockefeller Mountains have close affinities with the high sodium- and potassium-bearing rocks of East Antarctica, and show little affinity with the high calcium-, magnesium-, and iron-bearing rocks of the Andes of South America and the Antarctic Archipelago."

The northwestern part of Marie Byrd Land has now been added to the known areas. This reduces by several hundreds of miles the length of the unknown in this very important region about which there has been so much speculation. Our new knowledge does not entirely answer the questions, but does give valuable hints as to the solutions of the problems.

The eruptives of northwest Marie Byrd Land are high in sodium and potassium and are in this respect analogous to those of East Antarctica. However, the presence of zoned plagioclases in many of the intrusives suggests a relationship with the rocks of West Antarctica. Structurally

[13] Duncan Stewart, Jr.: *op. cit.*

the area is more like West Antarctica, for it is a region of intense folding and massive intrusions.

In November 1935, Ellsworth definitely established the continuity of land from Hearst Land to the Ross Sea.[14] South of Stefansson Strait he discovered three mountain ranges. Joerg[15] has analyzed the results of the Ellsworth flights and has suggested that these "results seem to confirm not only the conjectured southern continuation of the Antarctandes but also the virgation, or spreading, of their axes forecast by the Swiss geologist Staub"[16] (Fig. 2).

In the light of this new knowledge it seems probable that the Edsel Ford Mountains are a continuation of the northernmost of the three axes. This axis seems in turn to divide in the Edsel Ford Mountains, one of the sub-axes trending northward and the other to the northwest. The latter possibly continues on the eastern side of Sulzberger Bay as the mountains of King Edward VII Land.

The petrographic evidence does not appear to support fully these deductions as the rocks apparently have closer affinities with those of East Antarctica. The granitic intrusives of East Antarctica have been placed in the pre-Cambrian.[17] The age of the granite-granodiorite intrusions into Marie Byrd Land has not been definitely determined, but they have followed the period of folding of the sedimentary formations which certainly must be younger than pre-Cambrian. Correlation between the two is therefore impractical. If the Edsel Ford Mountains are considered to be one of the blind ends of the virgated Andean system, the intrusives might then be considered as high sodic and potassic differentiates of the same magma which was intruded farther to the east in the more central portion of the range.

The true solution of this problem will be known only after considerably more field work has been done in the newly discovered mountains of Hearst and Ellsworth lands and in the Edsel Ford Range. The problem is a most interesting one to both petrographers and structural geologists. Further exploration in these areas should indeed prove to be well worth while.

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[14] Lincoln Ellsworth: *My flight across Antarctica*, Nat. Geogr. Mag., vol. 70 (1936) p. 7-26.

[15] W. L. G. Joerg: *The topographical results of Ellsworth's trans-Antarctic flight of 1935*, Geogr. Rev., vol. 26 (1936) p. 454-462.

[16] Rudolf Staub: *Der Bewegungsmechanismus der Erde*, (1928) p. 117-118; map in pocket, Berlin.

[17] Griffith Taylor: *op. cit.*, p. 106.

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SOME GEOGRAPHICAL RESULTS OF THE SECOND BYRD ANTARCTIC EXPEDITION, 1933-1935

II

NORTHEASTERN BORDERLANDS OF THE ROSS SEA: GLACIOLOGICAL STUDIES IN KING EDWARD VII LAND AND NORTHWESTERN MARIE BYRD LAND

BY

F. ALTON WADE

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II

NORTHEASTERN BORDERLANDS OF THE ROSS SEA: GLACIOLOGICAL STUDIES IN KING EDWARD VII LAND AND NORTHWESTERN MARIE BYRD LAND

F. Alton Wade

IN "Problems of Polar Research" the northeastern borderlands of the Ross Sea—King Edward VII Land and "the lands beyond"—are described as "one of the crucial areas and problems" of the Antarctic: little was known of the area at the time this was written.[1] The First Byrd Antarctic Expedition was able to unveil some of its mysteries. The Rockefeller Mountains, southwest of the Alexandra Mountains, were discovered by Admiral Byrd from the air early in 1929 and were visited by Gould shortly afterward for a reconnaissance survey.[2] Late in 1929, on his important flight northeastward from Little America, Byrd discovered the Edsel Ford Range and named this part of "the lands beyond" Marie Byrd Land. On the Second Byrd Antarctic Expedition, during the summer of 1934–1935, the region was observed from many angles, and more secrets were uncovered. This article is concerned with the geographical and glaciological results obtained by the several parties in the region—the sledge party, of which I was a member,[3] the two tractor parties that entered the area, and the four exploratory flights made over it.

King Edward Vii Land

Is King Edward VII Land insular or peninsular? We believe that the data collected by the three field parties working therein and the observations and aerial photographs taken during the flights definitely prove the peninsularity of this land.

The base-laying tractor party, which preceded our sledge party as far as Mt. Grace McKinley, found its way blocked by a system of huge crevasses (Fig. 2) at a point a few miles southeast of the Rockefeller Mountains. This disturbed area was made up of tension cracks, formed where the ice flowed downward from the high land of the peninsula to the level of the Ross Shelf Ice. A passage through the crevasses was found five miles farther south. The ascent began there and continued in huge, terracelike steps for nearly 70 miles. The change in altitude along the trail was from 359 feet on the Ross Shelf

[1] R. E. Priestley and C. E. Tilley: Geological Problems of Antarctica, *in* Problems of Polar Research, *Amer. Geogr. Soc. Special Publ. No. 7*, 1928, pp. 315–328, reference on p. 320.

[2] R. E. Byrd: The Flight to Marie Byrd Land, *Geogr. Rev.*, Vol. 23, 1933, pp. 177–195; L. M. Gould: Some Geographical Results of the Byrd Antarctic Expedition, *ibid.*, Vol. 21, 1931, pp. 177–200.

[3] The sledge party, led by Paul A. Siple, included Stevenson Corey, Olin D. Stancliff, and myself. The party traveled more than 800 miles between October 15 and December 29, 1934. For narrative reports of this and the other explorations in the area see R. E. Byrd: Discovery, New York, 1935.

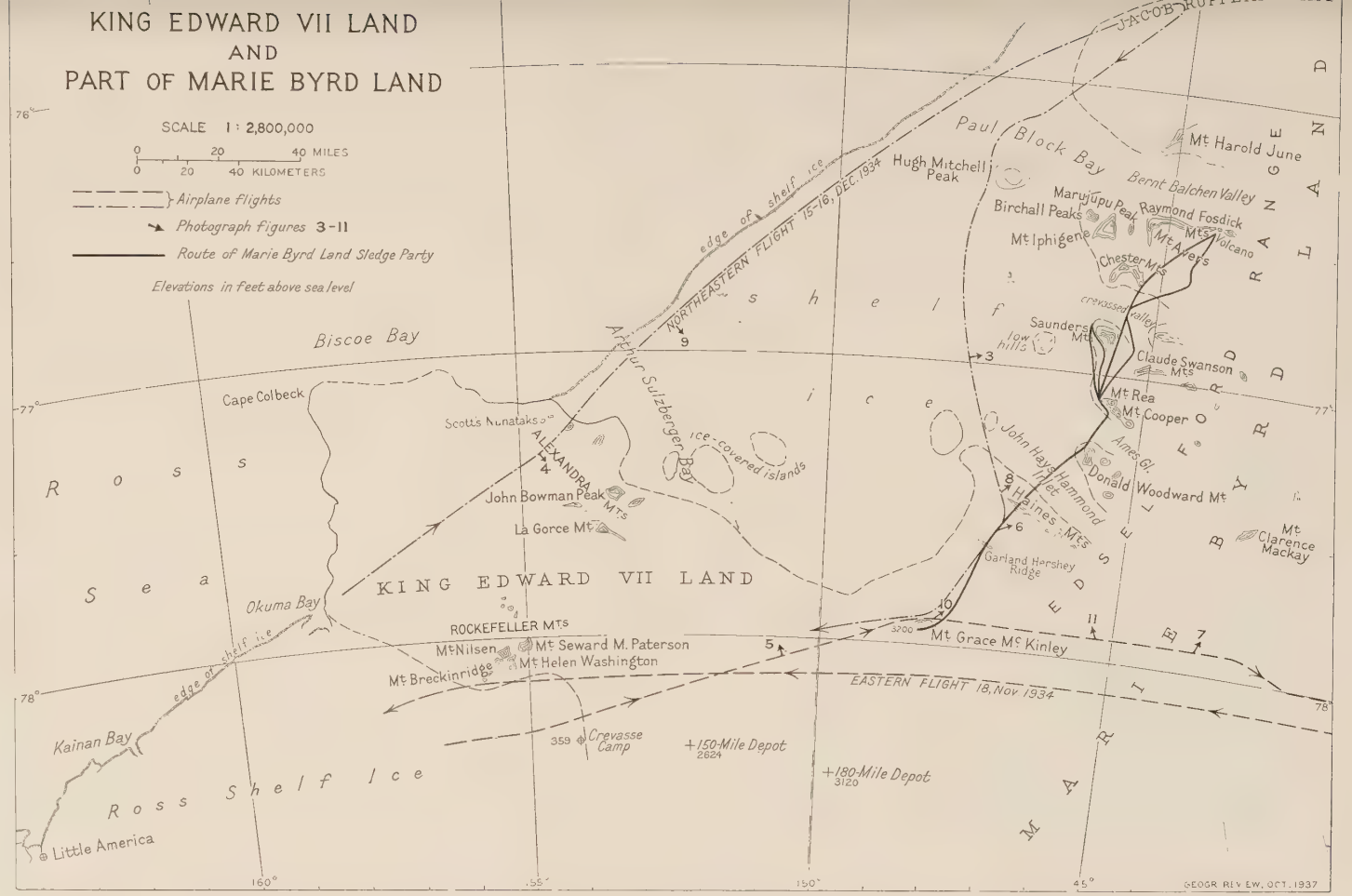

FIG. 1 Sketch drawn from the reconnaissance map of the northeastern borderlands of the Ross Sea now in preparation by Commander H. E. Saunders. Beside the data obtained by the several parties of the Second Byrd Antarctic Expedition at work in the region use is being made of the aerial photographs obtained by the first expedition, reinterpreted in the light of the additional control points (compare Commander Saunders' map accompanying R. E. Byrd: The Flight to Marie Byrd Land, *Geogr. Rev.*, Vol. 23, 1933, pp. 177–209).

FIG. 2—Giant crevasses characterize the steep border slopes between King Edward VII Land and the Ross Shelf Ice.

Ice to nearly 3600 feet at the crest. The descent to the level of the Shelf Ice near Mt. Grace McKinley (Fig. 1) was more rapid but also steplike. The observations of the tractor party were confirmed by our observations later in the season.

At many points along the trail in the vicinity of 150-mile depot we could see La Gorce Mountain far to the northwest, and at times we were certain that we could see the ice sheet sloping gently downward to this mountain. But one cannot rely on sight alone to establish topographic features in an ice-covered region. For instance, on the outward trip I believed I could see a deep valley separating the Rockefeller Mountains from the Alexandras and so reported to Little America by radio. However, on a flight across this area Admiral Byrd, by means of air soundings, proved that the valley did not exist and that the peninsula included all the mountain groups of King Edward VII Land.

The crevassed area just noted is one of many along this western shore line. The steep slope of the land is reflected on the ice surface by these disturbed areas, but the pronounced change in slope of the ice itself along this line would be enough evidence to indicate and prove

FIG. 3—An ice-capped island near the eastern edge of the Shelf Ice (off Saunders Mt.).

the existence of this coast. The eastern shore line of the peninsula also is characterized by steep, deeply crevassed slopes. It was observed from the plane from many angles and has, in fact, been seen in its entirety. This shore line can be readily picked out in any of the many aerial photographs taken of this region on the several flights.

The southeastward extension of the peninsula to join the Rockefeller Plateau was proved by the altitude observations of the tractor party. The fact that this ice was definitely resting on land above sea level was established by C. G. Morgan, a member of this party. By means of seismic soundings he determined the thickness of the ice at 25-mile intervals along their route. The greatest thickness recorded was 2100 feet, at an altitude of 3200 feet back of the Alexandra Mountains.[4]

No abrupt change in topography was noted by Ellsworth on his trans-Antarctic flight[5] as he flew from above the higher Hollick-Kenyon Plateau to the lower Rockefeller Plateau. This would indicate an uninterrupted continuation of the underlying land.

The peninsula extends northwestward from the higher mountains

[4] Byrd, Discovery, p. 318, footnote 16.

[5] "Lincoln Ellsworth's Flight Across West Antarctica," *Geogr. Rev.*, Vol. 26, 1936, pp. 329–332.

FIG. 4

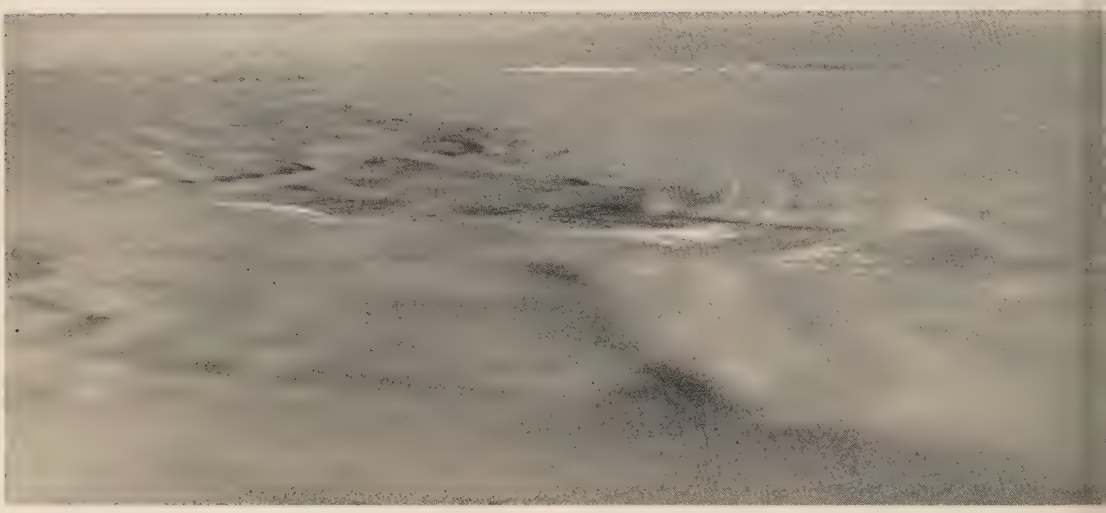

FIG. 5

FIG. 6

FIG. 4—A line of ice-covered cliffs extending northwest from La Gorce Mountain, in King Edward VII Land.

FIG. 5—Steep, crevassed slopes mark the position of the northeast coast line of King Edward VII Land peninsula. Two ice-capped i can be seen protruding through the shelf ice in Arthur Sulzberger Bay.

FIG. 6—The Edsel Ford Range looking north-northeast, from the Raymond Fosdick Mountains and Saunders Mountain on the John Hays Hammond Inlet at the right, with the Haines Mountains in the foreground.

FIG. 7

FIG. 8

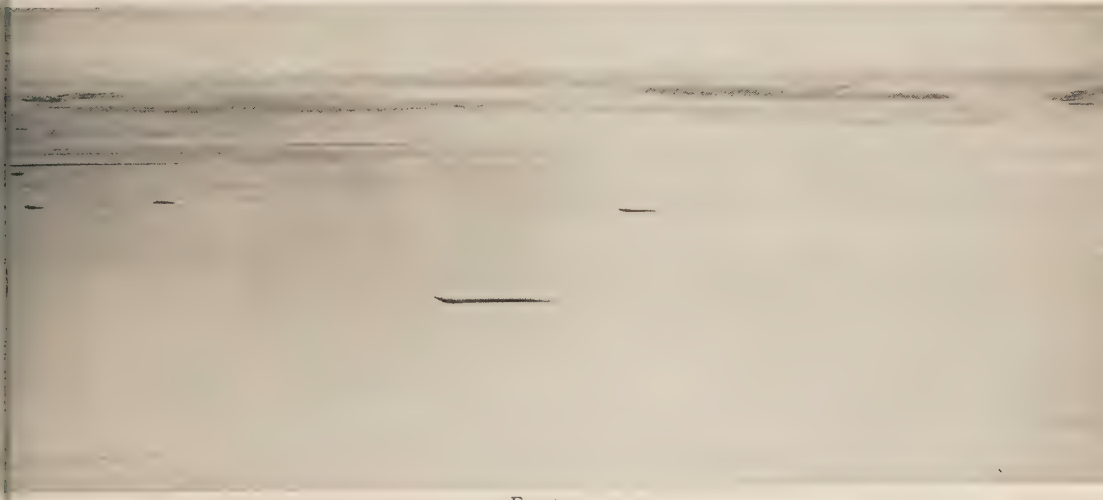

FIG. 9

7—The terraced descent from the Rockefeller Plateau to the lower level of John Hays Hammond Inlet.
8—The seaward extension of the Haines Mountains appears as an ice-capped ridge in the foreground. Raymond Fosdick Mountain
unders Mountain at left; Mt. Rea and Mt. Cooper in center.
9 Ice capped islands (the three masses in the background) in Arthur Sulzberger Bay. Embedded icebergs in the foreground.

of King Edward VII Land to Cape Colbeck. The pronounced irregularities noted and photographed in this area indicate topographic features on land beneath the ice sheet. Presumably the ground surface slopes gradually downward as Cape Colbeck is approached, but any peaks or ridges that may exist are not high enough to protrude through the ice. The fact that Cape Colbeck, which is indeed only an ice cape, has remained fixed in position for nearly thirty-five years supports the assumption that the ice is definitely grounded at this point. The echo soundings taken during the eastern cruise of the *Bear* indicate that the peninsula continues as a submarine ridge in the Ross Sea.[6] Also indicative of the peninsularity of King Edward VII Land are the air-sounding data obtained by Rawson on the flights over this area. The "soundings" were obtained by skimming the surface and reading the plane's altimeter.

Shelf Ice Between the Edsel Ford Range and the Alexandra Mountains

The area between the Edsel Ford Range and the Alexandra Mountains, which includes Paul Block Bay, John Hays Hammond Inlet, and Arthur Sulzberger Bay, offers an opportunity to study a sheet of shelf ice of moderate size. Our sledge party traversed parts of this formation along its eastern edge, and it was observed and photographed in its entirety by the flight crew on three separate occasions.

Shelf ice may be roughly defined as a floating piedmont. Such sheets, if formed in an indentation of the shore line, as this one is, conform in shape to the limiting boundaries of the indentation and have fairly straight, clifflike faces on the seaward side. The course of our sledge party brought us into the Edsel Ford Range at Mt. Grace McKinley. From the crest of the pink cliffs one can see the greater part of this Shelf Ice stretching seaward, bounded on the northeast by the majestic peaks of this mountain range and on the west by the lower ridges of the Alexandra Mountains, over which the inland ice that caps the King Edward VII Land peninsula pours brokenly. As the icecap decreases in height toward the sea, the peaks of the Alexandras appear and become the restraining wall that borders the northwest extremity of this area.

In its central part the Shelf Ice stretches without a break, except in the vicinity of islands, and slopes gently downward from an altitude of about 2400 feet at the foot of Mt. Grace McKinley to less than a hundred feet at the seaward edge. The entire western shore line of Arthur Sulzberger Bay is distinctly marked by steep slopes where the ice moves downward from the peninsula to the lower level of the bay.

[6] See the preceding article by S. E. Roos: The Submarine Topography of the Ross Sea and Adjacent Waters.

The areas of tension cracks on these slopes are numerous and significant. Leading out from these disturbed areas are large undulations that curve toward the head of the bay, thus indicating that the main ice movement is in that direction (Fig. 5).

The northeastern shore line is highly irregular (Fig. 6). The Edsel Ford Range has been deeply carved by the valley glaciers of the past. Were the ice removed, we should have here a magnificent fiord country. At the head of the inlets the inland ice descends from the higher plateau level to the lower inlet level in broad, terracelike undulations. Where this descent is gradual, as it is at the head of John Hays Hammond Inlet, few crevasses are present (Fig. 7); where the descent is rapid, there are numberless enormous crevasses. Ice-covered ridges extend out from the high land (Fig. 8), and the ice is always greatly crevassed along their margins. Small pressure rolls with axes normal to the direction of maximum slope are generally found at the foot of the slopes on each side of the ridges.

The islands in the Shelf Ice are completely ice-capped. Those near the eastern edge, where the ice is comparatively thick, from a distance and from the air resemble huge pimples on the surface (Fig. 3). The slopes on their borders are fairly gentle; crevasses, naturally, are present, but there is no sharp break in the topography. The islands near the outer edge of the Shelf Ice are distinctly characteristic of a later stage in the glacial cycle. The shelf ice here is comparatively thin and does not override these islands as it did in the past. Many of the gentle slopes have been replaced by sheer cliffs or steep, irregular slopes. It is evident that the seaward face of the ice recedes periodically. Figure 9 shows pieces broken off from the sheet late in an open season and now held fast in newly formed sea ice.

The surface features of the shelf ice, with its characteristic *zastrugi*, were much the same as those observed on the Ross Shelf Ice and on the Rockefeller Plateau.

As our time in this area was so short, and as we seldom visited the same spot twice, it was impossible to take any satisfactory measurements of the rate of movement of the ice. At only one point was a study of the character of the ice made. At a spot a few miles northwest of Saunders Mountain Stancliff descended 30 feet into a crevasse. He reported that the formation was here composed entirely of névé. No glacial ice was observed and no stratification noted.[7]

The Formation of Shelf Ice

Many theories have been advanced to explain the origin of shelf ice in general and of the Ross Shelf Ice in particular. The Ross sheet,

[7] This agrees with other observations made by this expedition but is contrary to previous reports of regular stratification. For example, Dr. Poulter found the layers on the walls of a 30-foot shaft at Little America so short that they could not be traced across the two opposite sides, only four feet apart.

FIG. 10—Icefalls along the ridge east of Mt. Grace McKinley.

as largest existing example of this type of ice formation, has naturally received most attention. Unfortunately, however, all theories regarding its history and origin are based on observations limited to its border areas. Most of the central part has never been seen by man. In his recent paper on "The Ross Shelf Ice"[8] Gould briefly discusses previous theories before presenting his own views:

> The present Ross Shelf Ice is the product of two sets of causes which have rarely, if ever, operated separately. Ice tongues from the inland ice, expanding and coalescing to form piedmonts, have functioned with areas of fast ice to form rafts, or basements, upon which snow has accumulated to become compacted into neve. Melting from below has obliterated the original, or youthful, pattern of the Ross Shelf Ice.

[8] L. M. Gould: The Ross Shelf Ice, *Bull. Geol. Soc. of America*, Vol. 46 (Part 2), 1935, pp. 1367–1393; reference on p. 1393.

FIG. 11—A step in the terraced descent to the Shelf Ice. Here the Haines Mountains (in the background) hold the advancing ice sheet in check.

To this a new point may be added in explanation of the origin of the Shelf Ice under discussion. In the earlier phases of the Glacial period mighty glaciers cut through the coastal ranges and advanced into the bay in the form of floating ice tongues. At the same time icecaps were forming and ever increasing in size on the islands in the bay. Eventually the marginal piedmont, formed by the confluence of the ice tongues, combined, with the aid of interstitial sea ice, with the island ice to form the embryonic shelf ice. It is everywhere evident among the peaks of the Edsel Ford Range that there was a period of much greater glacierization,[9] and very probably the

[9] Using the term suggested by Wright and Priestley. C. S. Wright and R. E. Priestley: Glaciology. British (Terra Nova) Antarctic Expedition, 1910–1913, London, 1922.

inland ice of that time flowed over the mountains in an unbroken sheet and completely filled the bay. Possibly more islands existed then, before the continental depression under isostatic adjustment to the increased load of the icecap at the time of maximum glaciation.

To apply this theory of origin to all formations of shelf ice is not my intention. However, as will be pointed out in a later article,[10]

FIG. 12—From the south the ice sheet slopes gradually upward to the crest of Mt. Grace McKinley.

the role of island ice in the origin of the Ross Shelf Ice is of primary importance and must be given due consideration in theories of shelf-ice formation in general.

THE EDSEL FORD RANGE

The Edsel Ford Range owes its configuration to the combined results of the folding of a series of sedimentary formations, the intrusion of great igneous masses, and the erosive action of local glaciers and continental ice sheets. Structurally the range would seem to resemble more nearly the Graham Land region of West Antarctica than the East Antarctic horst. On the other hand, petrographic examination of the igneous rocks shows them to be of the high sodium and potassium "Atlantic" type rather than the basic "Pacific" type of West Antarctica.[11] Solution of this problem of geological and

[10] By T. C. Poulter and F. A. Wade. In preparation.

[11] Analyses in "Petrologic and Structural Relations of the Edsel Ford Range with Other Antarctic Mountains," to be published in the *Bulletin of the Geological Society of America.*

Compare Duncan Stewart, Jr.: A Contribution to Antarctic Petrography, *Journ. of Geol.*, Vol. 42, 1934, pp. 546–550, for an analysis of rocks collected by Gould in the Queen Maud and the Rockefeller Mountains. "It is concluded that the rocks of the Rockefeller Mountains have close affinities with the high sodium- and potassium-bearing rocks of East Antarctica, and show little affinity with the high calcium-, magnesium-, and iron-bearing rocks of the Andes of South America and the Antarctic Archipelago" (p. 550).

physiographic relationships awaits more field work in the region and in Hearst and James W. Ellsworth Lands.[12] The Edsel Ford region offers readier scope for the study of glacial phenomena.

The icecap which forms the Rockefeller Plateau is impeded in its progress seaward by the mountains of the Edsel Ford Range. As one journeys in a northeasterly direction past Mt. Grace McKinley

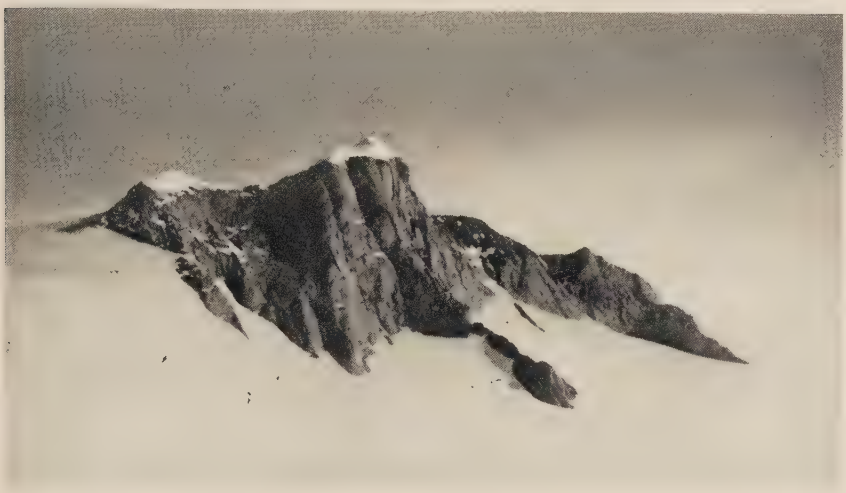

FIG. 13—The northern face of Mt. Grace McKinley is an almost perpendicular wall.

and on through the range, the terraced aspect of the fringe of the icecap is very evident. The southern and southeastern snow-covered slopes of Mt. Grace McKinley rise gently to the topmost peaks (Fig. 12) and on the farther side drop in precipitous cliffs eight hundred to a thousand feet high (Fig. 13). The lower peaks of the ridge on each side of the mountain are not high enough to protrude through the ice but do act as a dam, and the ice falls over the ridge to a level some six hundred feet lower. Huge crevasses characterize these ice-falls (Fig. 10). From the foot of this step the ice surface rises gradually to Garland Hershey Ridge and falls to a new low on the seaward side. The Haines Mountains may be considered a third step in the terrace (Fig. 11). As the principal movement of the ice is down the valleys towards the Shelf Ice, the gradual increase in thickness of the ice as one travels northward between the ridges is probably due to the accumulation of wind-driven snow in the lee of the ridges.

The icecap has receded sufficiently to leave the more northern peaks—Mts. Cooper, Rea, Saunders, the Chester Mountains, etc.—bare of ice and snow except on flat crests and in local catchment basins. Valleys have been carved through the range by glaciers of

[12] W. L. G. Joerg: The Cartographical Results of Ellsworth's Trans-Antarctic Flight of 1935, *Geogr. Rev.*, Vol. 27, 1937. pp. 430–444.

FIG. 14

FIG. 15

FIG. 16

FIG. 14—Looking down across the terraced terminal moraine, Mt. Rea, to a blue-ice lake below.
FIG. 15—Highland ice topping the lower peaks of Mt. Rea.
FIG. 16—A lateral moraine near Mt. Rea.

the past; today the glaciers in these valleys are comparatively thin, slowly moving sheets of ice that descend gently from the base of the steep slopes and icefalls at their heads to their outlets at the Shelf Ice. That they are not stagnant is evidenced by the disturbed shear areas along their borders. The area of greatest disturbance that we noted was a narrow zone parallel to Mts. Rea and Cooper at a distance of about a mile. It was characterized by numerous small crevasses and "haycocks," many of the latter rising to a height of more than six feet.

Siple and Corey were forced to detour round an extensive deeply crevassed region (76° 45′ S., 145° 30′ W.) while on their trek into the northeastern part of the range. This disturbed area occupies a large basin of 25 to 30 square miles, surrounded by mountains. The crevasses, except for the marginal shear cracks, are mostly tension cracks, formed as the thin ice passes over irregularities in the basin floor.

In the vicinity of the bare rock peaks many small, blue-ice lakes were observed. During the midsummer days much snow melts on the mountain slopes near the bare exposures and runs off into the snow fields at the foot of the slopes, where it mixes with the unconsolidated snow, freezes, and forms this hard, so-called "blue ice."

Many indications of former greater glacierization were seen. The flat, bare exposures on the heights of Mt. Grace McKinley and on Garland Hershey Ridge are deeply gouged and striated. The rather flat crest of Mt. Donald Woodward, about six hundred feet above the present level of the broad valley glaciers on each side, is deeply striated and exhibits chatter marks and crescentic gouge marks.

The most striking evidence came from the Rea-Cooper massif, the highest of whose precipitously cliffed, pink, granite peaks rises 2800 feet above the level of the shelf ice. Remnants of mountain-glacier valleys may be observed at many points. One peak in particular owes its peculiar pyramidal shape to the cutting action of glaciers on three sides. Great piles of morainic material lie at the bases of the three slopes. One of these piles, arranged in terraced steps, was interpreted as a receding series of terminal moraines (Fig. 14). An unmistakable U-shaped glacial valley cutting across one of the higher peaks of the massif implies a former active mountain glacier at a level 2000 feet higher than that of the nearest active ice today. The sheer cliffs characteristic of this mountain owe their formation to the splitting off of huge tabular slabs as a result of frost action along vertical joints. Many glacial features have thus been erased. Two moraines, the only extensive lateral moraines observed throughout the entire area, extend out for about two miles from the western base of Mt. Rea in a thin ice area (Fig. 16). All other glacier-transported debris has disappeared from sight in the ice of the slow-moving outlet glaciers.

VITA

Franklin Alton Wade was born in Akron, Ohio, February 5, 1903. He received his elementary and secondary training in the Akron Public Schools and was graduated from Western Reserve Academy, Hudson, Ohio, in June 1921. He received his undergraduate training at Kenyon College, from which institution he received the degrees of Bachelor of Science in 1925, and Master of Arts in 1926. Since then his time has been occupied as follows:

1926-27—Instructor in Chemistry and English, St. George's School, Newport, Rhode Island.
1928-29—Instructor in Chemistry, Palmer Junior College, Albany, Missouri.
1929-31—Instructor in Geology and Chemistry, University of Delaware, Newark, Delaware.
Summer 1930—Graduate Student in Chemistry, University of Michigan, Ann Arbor, Michigan.
1931-32—Graduate Student in Chemistry, The Johns Hopkins University, Baltimore, Maryland.
1932-33—Graduate Student in Geology, The Johns Hopkins University, Baltimore, Maryland.
Summer 1933—Geologic Field Work. Knox County, Maine.
1933-35—Geologist with the Byrd Antarctic Expedition II.
1935-36—Graduate Student in Geology, The Johns Hopkins University.
1936-37—Instructor in Geology, Miami University, Oxford, Ohio.
Acting Chief Geologist, Byrd Antarctic Expedition II.